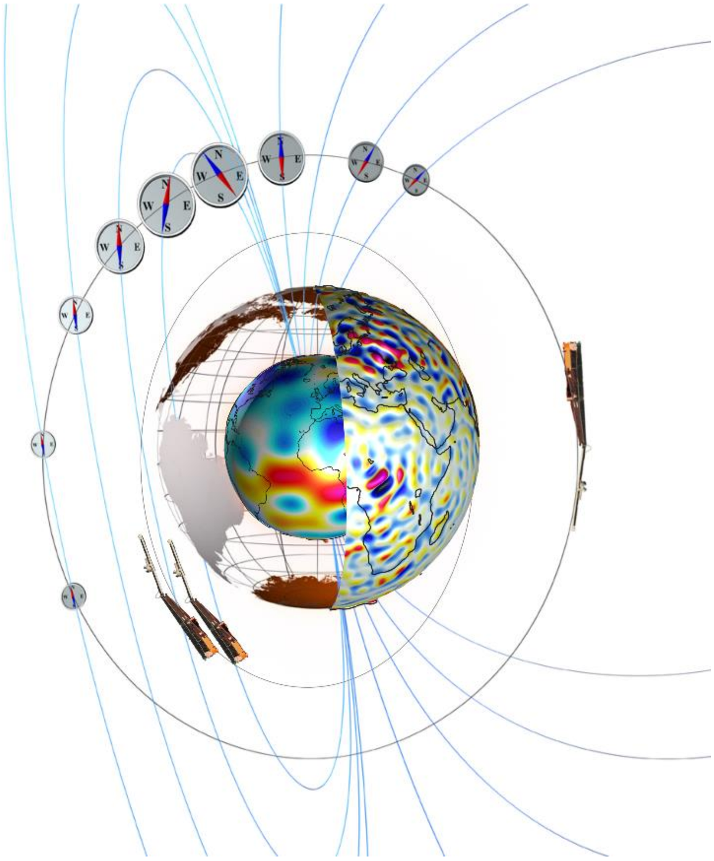
EFI TII Cross-Track Flow Data Release Notes



Doc. no: SW-RN-UoC-GS-004, Rev: 6, 16 June 2020

Prepared:

Johnathan Burchill Date 16 June 2020

EFI Scientist

Approved:

David Knudsen Date 16 June 2020

Team Manager

© University of Calgary, Canada, 2020. Proprietary and intellectual rights of University of Calgary, Canada are involved in the subject-matter of this material and all manufacturing, reproduction, use, disclosure, and sales rights pertaining to such subject-matter are expressly reserved. This material is submitted for a specific purpose as agreed in writing, and the recipient by accepting this material agrees that this material will not be used, copied, or reproduced in whole or in part nor its contents (or any part thereof) revealed in any manner or to any third party, except own staff, to meet the purpose for which it was submitted and subject to the terms of the written agreement.

Record of Changes

Reason	Description	Rev	Date
Initial vers.	Draft	1 dA	1 Nov 2016
Revision	Updated based on community feedback and further revision and elaboration of calibration procedure.	1 dB	1 Feb 2017
Revision	Grammatical fixes and clarifications.	1dC	1 Feb 2017
Revision	Incorporated feedback from DTU: Figure labels, Tables of Figures and Tables, cross-referencing, order of variables in CDF file, CDF file version numbering, reference document. Fixed longitude interpolations.	1	6 Feb 2017
Revision	Clarify interpretation and issues with quality flags; grammatical fixes.	2dA	13 Apr 2017
Revision	Updated date and clarified suitability of H sensor data for publication. Signed.	2	16 May 2017
Revision	Added notes about 16 Hz cross-track data.	3dA	12 Sep 2017
Revision	Incorporated feedback from DTU: fixed description of 16 Hz ion velocity components and removed paragraph about zip archiving. Signed.	3	25 Sep 2017
Revision	Updated for version 0201, with new CDF contents and processing algorithm.	4dA	13 Jan 2020
Revision	Update based on feedback from DTU: TIICT product name used throughout; Table numbering fixed; Unit and description of 0201 Time variable unified with other products; Table caption formatting; Removed duplicate panel in Figure 3-1. Signed and released.	4	5 Feb 2020
Revision	Added a note about Swarm C calibration and flagging to the Known Limitations for version 0201.	5dA	2 Mar 2020
Release	Signed and released.	5	3 Mar 2020
Revision	Added a note about overestimate of drifts and fields in version 0201 for measurements made prior to mid 2018. New version 0202 described, with updated CDF file format.	6dA	5 May 2020
Revision	Changed version 0202 to 0301 due to significant changes in processing and file format. Updated flagging definitions. Included feedback from DTU on revision 6dA. Further elaboration of processing and flagging methods. Added flag examples.	6dB	15 June 2020

Reason	Description	Rev	Date
Revision	Added reference to changes from 0202 to 0301 in Section 3.2.1. Corrected MLT units in table 3-4. Signed and released.	6	16 June 2020

Table of Contents

Table of Figures

Table of Tables

1 Introduction

1.1 Scope and applicability

This document describes the University of Calgary EFI TII cross-satellite-track ion flow dataset.

2 Applicable and Reference Documentation

2.1 Applicable Documents

None.

2.2 Reference Documents

RD1 Knudsen, D. J., J. K. Burchill, S. C. Buchert, A. I. Eriksson, R. Gill, J.-E. Wahlund, L. Åhlen, M. Smith, and B. Moffat (2017), Thermal ion imagers and Langmuir probes in the Swarm electric field instruments, J. Geophys. Res. Space Physics, 122, doi:10.1002/2016JA022571.

RD2 Lomidze, L., J. K. Burchill, A. Kouznetsov, D. R. Weimer (2019), Validity Study of the Swarm Horizontal Cross-track Ion Drift Velocities in the High-latitude Ionosphere. Earth and Space Science.

RD3 Koustov, A. V., Lavoie, D. B., Kouznetsov, A. F., Burchill, J. K., Knudsen, D. J., & Fiori, R. A. D (2019), A comparison of cross-track ion drift measured by the Swarm satellites and plasma convection velocity measured by SuperDARN. J. Geophys. Res. Space Physics.

RD4 Swarm Level 1b Product Definition, SW-RS-DSC-SY-0007.

RD5 GNU Scientific Library (GSL) version 2.6 online documentation, as accessed at https://www.gnu.org/software/gsl/doc/html/index.html on 4 May 2020.

2.3 Abbreviations

Acronym ***or abbreviation***	***Description***
DISC	Data, Innovation, and Science Cluster
ESA	European Space Agency
L1b	Level 1b (satellite data)
Swarm	Constellation of 3 ESA satellites, http://www.esa.int/esaLP/ESA3QZJE43D_LPswarm_0.html
Swarm DISC	Swarm Data, Innovation, and Science Cluster
TBD	To Be Defined
TBS	To Be Specified
TII	Thermal Ion Imager, part of the Swarm Electric Field Instrument package
UoC	University of Calgary, CA

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

3 TII cross-track ion flow data

3.1 Overview

This release note describes the Swarm EFI 2 Hz and 16 Hz TII Cross-Track Ion Flow data. University of Calgary has undertaken to simplify the TII Level 1b processing by deriving ion flow velocity components perpendicular to the satellite velocity vector. This has three expected benefits:

1. It removes the coupling of the less accurate along-track ion flows into the cross-track flows for non-zero pitch and yaw orientations of the satellite;
2. It makes routine calibrations and data selection feasible;
3. It enables routine TII flow data releases to the scientific community.

Version 0301 ion flows are calculated from the linear displacement of the ion signal in the cross-track direction, removing the assumption of zero along-track flow inherent in the 0101 dataset. Refer to Section 4.1 for notes about the Version 0301 data quality and known limitations. Questions about the cross-track flow data can be referred to Johnathan Burchill <jkburchi@ucalgary.ca>.

3.2 Methods of estimation

3.2.1 Version 0301

Ion flows are calculated from the onboard-derived 16 Hz *x* and *y* image moments (RD1), treating each direction independently. Refer to Section 4.1.1 for summary of changes with respect to version 0201.

The calibration is performed on daily intervals padded by approximately 25 minutes from the previous and following days, when those data are available. The procedure is as follows:

1. In-flight calibration of each TII sensor's measurement sensitivity consists of rotating each satellite in yaw or pitch by a known amount during one orbit, while the EFI TIIs are operated at a fixed inner-dome bias voltage. Only low and mid-latitude measurements are used for the calibration, where the ion drift is negligible in comparison with the satellite velocity. Because the sensitivity depends on the setting of the sensor bias voltage, which varies over the mission, the calibration parameter is updated for historical data through the use of instrument simulations of sensitivity versus sensor bias.
2. The sensor *x* direction (along-track) sensitivity (measured in m/s per pixel) is assumed to be the same as the horizontal *y* moment sensitivity.
3. Ion drift is calculated at 16 Hz for four components (along-track horizontal (H) sensor, along-track vertical (V) sensor, cross-track H sensor and cross-track V sensor) using the in-flight-determined calibration parameters after removal of estimated baselines.
4. For the purpose of calibration, measurements are grouped into high-latitude (polar) and low-latitude (equatorial) regions using a quasi-dipolar magnetic latitude boundary of 44 degrees.
5. For each interval, a linear trend is estimated for each velocity component using the GNU Scientific Library's *gsl_multi_robust_biquare* robust linear estimator (RD5). The fit points for estimating the linear trend in each polar region are taken from the interval [44, 50) degrees (quasi dipole) on either side of the north magnetic pole, and from (-50, -44] on either side of the south magnetic pole. The fit boundaries for the equatorial regions are from (-44, -38] and [38, -44) degrees for each interval.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

6. Linear estimates are made only if both ends of an interval have measurements. Linear trends are removed from each interval unless the fit fails. If either the fit fails or one end of the interval does not have measurements, a calibration flag is raised.
7. Random measurement error is estimated robustly with respect to exclusion of outliers for each velocity component using *gsl_multifit_robust_statistics* to estimate the median absolute deviation statistic of all mid-latitude fit residuals (RD2). The same error estimate is used for all measurements in a given fit interval. The error does not take into account possible ionospheric variability at mid-latitudes. A negative error value indicates that no estimate is available for that measurement.
8. A bitwise data quality flag for each velocity component is set if the random error as estimated from the median absolute deviation of the baseline fit residuals is less than 100 m/s, and if the ion drift magnitude is less than 8 km/s, and if a valid fit for the data interval has been found. The data quality flag bit is set to 0 otherwise.
9. All equatorial measurements are flagged as quality 0.
10. This procedure is applied equally to all four ion drift estimates for each satellite, including the two redundant along-track ion drifts.
11. No attempt is made to account for apparent along-track drift variations associated with variations in satellite floating potential, ion species composition, or out-of-plane ion drift. Consequently, all along-track ion drifts are flagged as quality 0.
12. Due to limitations of the in-flight calibrations, ion drift z-components (vertical) are currently flagged as quality 0, as are all components for the Swarm C ion drift.
13. Magnetic field vectors are derived from interpolated 1 Hz high-resolution magnetic field data product. These field vectors therefore contain no geophysical content at frequencies above 0.5 Hz.
14. Electric field in the plane normal to the geomagnetic field is estimated from $\mathbf{E} = -\mathbf{v} \times \mathbf{B}$.
15. Satellite positions are derived from interpolated 1 Hz MOD L1b measurements.
16. The 2 Hz data are down-sampled from 16 Hz using the mean of the eight measurements in each half-second. If less than 8 samples are available in a given half-second interval, that 2 Hz sample is discarded. Latitude and longitude are first transformed into cartesian coordinates before averaging, and the average values are transformed back. A similar procedure is used for averaging the quasi-dipole latitude and magnetic local time, converting MLT to a longitude for the purpose of averaging. Quality flags are down-sampled using the bitwise logical AND of the eight 16 Hz samples in each half-second interval. Calibration flags are down-sampled using the bitwise logical OR of the eight samples. The 8 km/s flow flag at 2 Hz therefore indicates that at least one of the eight 16 Hz samples used to estimate the 2 Hz sample had a flow magnitude exceeding 8 km/s.
17. Results of the linear model fits are stored for each day processed, available upon request by contacting the UCalgary EFI TII team.

3.2.2 Version 0201

Ion flows are calculated from the onboard-derived 16 Hz *x* and *y* image moments (RD1) averaged to 2 Hz, treating each direction independently. This is in contrast to the arrival-angle approach to deriving cross-track flow used in version 0101.

The calibration is performed as follows on weekly intervals for each month of data:

1. Moments are plotted in each of the three directions (along-track, cross-track horizontal, and cross-track vertical) against the corresponding known satellite velocity (including co-rotation drift and accounting for satellite attitude).

2. The sensor *y* direction sensitivity (m/s per pixel) is determined from an in-flight calibration whereby the satellite is rotated in yaw or pitch by a known amount during one orbit, while the EFI TIIs are operated at a known inner-dome bias voltage. Only low and mid-latitude measurements are used for the calibration, where the ion drift is negligible in comparison with the satellite velocity. Because the sensitivity depends on the setting of the sensor bias voltage, which varies over the mission, the calibration parameter is applied to historical data through the use of instrument simulations.
3. The sensor *x* direction sensitivity is assumed to be the same as the horizontal *y* moment sensitivity.
4. Ion drift is calculated for four components (along-track horizontal (H) sensor, along-track vertical (V) sensor, cross-track H sensor and cross-track V sensor).
5. Measurements are grouped into high-latitude and low-latitude regions using a quasi-dipolar boundary of 44 degrees. A linear trend is subtracted from each velocity component using the method described in RD2.
6. All equatorial measurements are flagged as quality 0 (use with extreme caution).
7. High-latitude measurements are flagged as quality 1 (use in consultation with EFI team) if background and noise levels are smaller than criteria determined in RD2.

No attempt is made to account for apparent along-track drift variations associated with variations in satellite floating potential, ion species composition, or out-of-plane ion drift.

3.2.3 Version 0101

Version 0101 cross-track flows are calculated as follows:

$$v_{iy} \approx v_{sat,H} \tan(\phi_{H} - \phi_{sat,H} + \phi_{1,H} + \phi_{2,H}) \text{ m/s} \quad \text{Equation 1}$$

$$v_{iz} \approx v_{sat,V} \tan(\phi_{V} - \phi_{sat,V} + \phi_{1,V} + \phi_{2,V}) \text{ m/s} \quad \text{Equation 2}$$

where v_{sat} is the satellite speed; ϕ_{H} and ϕ_{V} are the measured angular displacements of the oxygen ion signal within the horizontal (H) and vertical (V) detector planes, respectively; $\phi_{sat,H}$ and $\phi_{sat,V}$ are the angular signals due to the satellite motion and co-rotation, and include yaw and pitch variations relative to the nominal flight orientation; $\phi_{1,H}$ and $\phi_{1,V}$ are calibration parameters that depend on time since high voltage activation, $\phi_{2,H}$ and $\phi_{2,H}$ are high-latitude (polar region) calibration parameters, and v_{cr} is the co-rotation speed of the plasma at the satellite altitude. Both v_{sat} and v_{cr} take into account orbital inclinations of ~88.5 degrees. Measuring along-track ion flows on a satellite platform which moves at approximately 7.6 km/s is difficult, and it is not uncommon on other missions (e.g., DMSP, DE2, etc.) to provide cross-track flows derived in a manner akin to Equations 1 and 2 above.

The 2 Hz dataset is based on the 16 Hz first moments (*x* and *y*), which have been averaged down to a 2 Hz sample rate from which the flow angles are calculated for each TII sensor. Higher resolution data are provided in separate files.

The coordinate system used in Equations 1 and 2 is a right-handed orthonormal system defined in a frame of reference co-rotating with the Earth and having *x* in the direction of the satellite velocity, *y* perpendicular to *x* and horizontally to the right facing the direction of motion, and z approximately downward completing the triad.

Magnetic field measurements from the fluxgate magnetometer are transformed into this {*x,y,z*} coordinate system. Electric field is calculated from $-\vec{v} \times \vec{B}$ assuming the along-track ion flow is zero. Co-rotation velocity is always toward geographic east. It can be added to v_iy to obtain the approximate cross-track ion flow in the inertial frame. This transformation should be accurate to within a few m/s.

Calibrating the TII flow angles (and consequently the cross-track flows) is based on a three-step procedure to estimate angular offsets and to determine data quality. The first step involves applying estimated detector centre coordinates to determine sensor flow angles. This step is applied to all data and constitutes calibration level 0. Recent Swarm A operations have shown that measurements obtained within approximately 2.5 orbits of high-voltage turn-on are of lesser quality than those obtained after longer periods of operation. Such data remain calibration level 0 and should not be used in a scientific publication without first consulting the EFI Thermal Ion Imager team.

The second calibration step, level 1, removes a slowly varying bias as shown in the left panel of Figure 3-1. The red curve is a low-pass filtered median of all December 2016 flow angles from the Horizontal (H) sensor. The dashed black curve is a 2nd degree polynomial fit of the red curve between 14,100 s and 30,000 s. Data prior to 14,100 s (~2.5 orbits for Swarm A during December 2016) are flagged as calibration level 0 (detector centre calibration); data from 14,100 s onward are provisionally flagged as calibration level 1 before undergoing a final calibration and data selection step. Calibration level 1 data typically contain relatively large offsets that vary on timescales of an orbit (~95 minutes) or shorter. The functional form of the level 1 calibration varies from month to month and across sensors (e.g., Figure 3-1), and will be determined on a monthly basis. Currently all measurements at low latitude (i.e. within 30 deg. of the magnetic equator in quasi-dipole coordinates), as well as those in the nightside southern magnetic hemisphere (Swarm A), beyond the first one or two orbits are flagged as level 1. Such data may be publishable if care is taken to remove offsets and exclude or correct periods of anomalous TII sensor imaging.

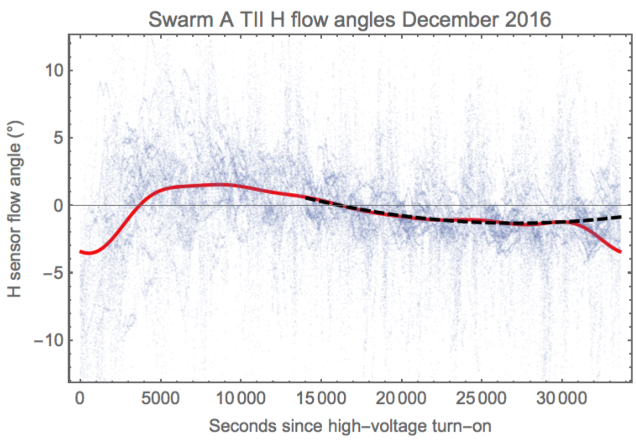


Figure 3-1: Level 1 offset correction.

This correction removes a systematic bias dependent on time since high-voltage turn-on. The level 1 correction can vary significantly month-to-month. See text for details.

As implemented, the level 1 offset calibration is influenced by outliers and anomalous signals which can lead to bias in the offsets. Level 2 calibration addresses this at high latitudes by removing a linear (with time) offset determined separately for northern and southern hemisphere polar region passes. A linear least-squares fit is made to time series of measurements between 30 deg. and 55 deg. quasi-dipole latitude on the ascending and descending sides of the magnetic pole for the H and V sensor angles separately. Figure 4-1 and Figure 4-2 show the results of the high-latitude calibrations. This procedure removes most of the bias at high latitudes in a majority of cases. An attempt is made to remove periods of obviously poor data quality (i.e. slowly varying large offsets) from the level 2 calibration by excluding data based on latitude and magnetic local time. Examples of the failure of the flagging algorithm to exclude poor measurements are identified in Section 4.

The level 1 and level 2 offset corrections are included in the datasets. The current algorithm assigns the same quality level to both cross-track flow measurements (y and z). That is, it tries to identify where both sensors provide good data.

3.3 Coordinate systems

The coordinate system for the satellite-track measurements (along- and cross-track) is a right-handed orthonormal system defined in a frame of reference co-rotating with the Earth and having *x* in the direction of the satellite velocity, *y* perpendicular to *x* and horizontally to the right when facing the direction of motion, and z approximately downward completing the triad.

Measurements may be transformed into the north-east-centre (NEC) system using the supplied satellite velocity vector in NEC coordinates as a reference.

3.4 Quality Flags

3.4.1 Version 0301

3.4.1.1 *Quality flag*

A quality flag is estimated automatically as part of the calibration procedure as described in Section 3.2.1. The flag is an unsigned 16-bit number whose bits represent the quality of different ion drift components:

- Bit 0 (least significant): $v_{i,x,H}$ (along-track component from the horizontal sensor)
- Bit 1: $v_{i,x,V}$ (along-track component from the vertical sensor)
- Bit 2: $v_{i,y}$ (to the right, observer facing forward)
- Bit 3: $v_{i,z}$ (downward)

A value of 1 is set only when all of the following are true:

- The magnitude of the ion drift is less than or equal to 8 km/s. Values in excess of 8 km/s may or may not be physically reasonable and require expert assessment.
- The median absolute deviation (MAD) of fit residuals for all mid-latitude data points used in the fit estimation is less than 100 m/s at 2 Hz, or 283 m/s at 16 Hz. The MAD is equivalent to the standard deviation (1-sigma deviation from mean) for normally-distributed measurements.
- The measurement is the cross-track horizontal flow measurement from Swarm A or Swarm B.
- Both ends of the fit interval have data points within the absolute value quasi-dipole latitude range [44, 50) degrees.
- The linear model fit was successful.

The quality of the electric field measurements may be assessed on the basis of the ion drift quality. It is currently not known which TII sensor provides the most reliable along-track ion drift estimates. The along-track components of ion drift and the electric field components most strongly influenced by them (E_y and E_z) should be interpreted with caution. The 2 Hz data are down-sampled from 16 Hz using the mean of eight measurements in each half second. A 2 Hz sample is not calculated if fewer than eight 16 Hz samples are available. The quality flag is set to 0 if any of the eight 16 Hz samples in the half second are flagged 0.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

3.4.1.2 *Calibration flag*

A calibration flag is provided as described in Section 3.2.1 and summarized in Table 3-1. The flag is an unsigned 32-bit number consisting of four groups of eight bits that represent the following information for each of the four velocity components:

- Bit 0 (least significant): 1 indicates that a background linear model offset was not removed.
- Bit 1: 1 indicates that this was an incomplete fit region, and therefore no background subtraction was performed. This can occur when EFI measurements start or stop within a given day.
- Bit 2: 1 indicates that the GNU Scientific Library reported a fit error.
- Bit 3: 1 indicates that the mid-latitude median absolute deviation threshold was exceeded (100 m/s at 2 Hz and 283 m/s at 16 Hz).
- Bit 4: 1 indicates that the 16 Hz ion flow magnitude exceeded 8 km/s.

Bits 5 through 7 of each group are reserved for future use. The bits are grouped as follows:

- Bits 0 to 7: vixh
- Bits 8 to 15: vixv
- Bits 16 to 23: viy
- Bits 24 to 31: viz

The baseline random noise threshold is 100 m/s at 2 Hz and 283 m/s at 16 Hz. The 2 Hz calibration flag is derived from the 16 Hz flag by setting each 2 Hz bit to 1 if any of the eight 16 Hz bits from the corresponding half second is 1. Figure 3-2 shows an example of cross-track horizontal (viy) ion flow and flags at 2 Hz from Swarm A on 17 July 2018. Examples of 2 Hz flag and calibration bits for all four flow parameters are shown in Figure 3-3 and Figure 3-4, respectively.

Table 3-1: Version 0301 calibration flag legend

TII parameter	Calibration flag bit							
vixh	7 → R	6 → R	5 → R	4 → FME	3 → BNE	2 → BFE	1 → IFR	0 → BNS
vixv	15 → R	14 → R	13 → R	12 → FME	11 → BNE	10 → BFE	9 → IFR	8 → BNS
viy	23 → R	22 → R	21 → R	20 → FME	19 → BNE	18 → BFE	17 → IFR	16 → BNS
viz	31 → R	30 → R	29 → R	28 → FME	27 → BNE	26 → BFE	25 → IFR	24 → BNS

BNS – 1 → baseline not subtracted
IFR – 1 → incomplete baseline fit region
BFE – 1 → baseline fit error
BNE – 1 → baseline random noise exceeds 100 m/s (1–sigma, 2 Hz equivalent)
FME – 1 → 16 Hz flow magnitude exceeds 8 km/s
R – reserved

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

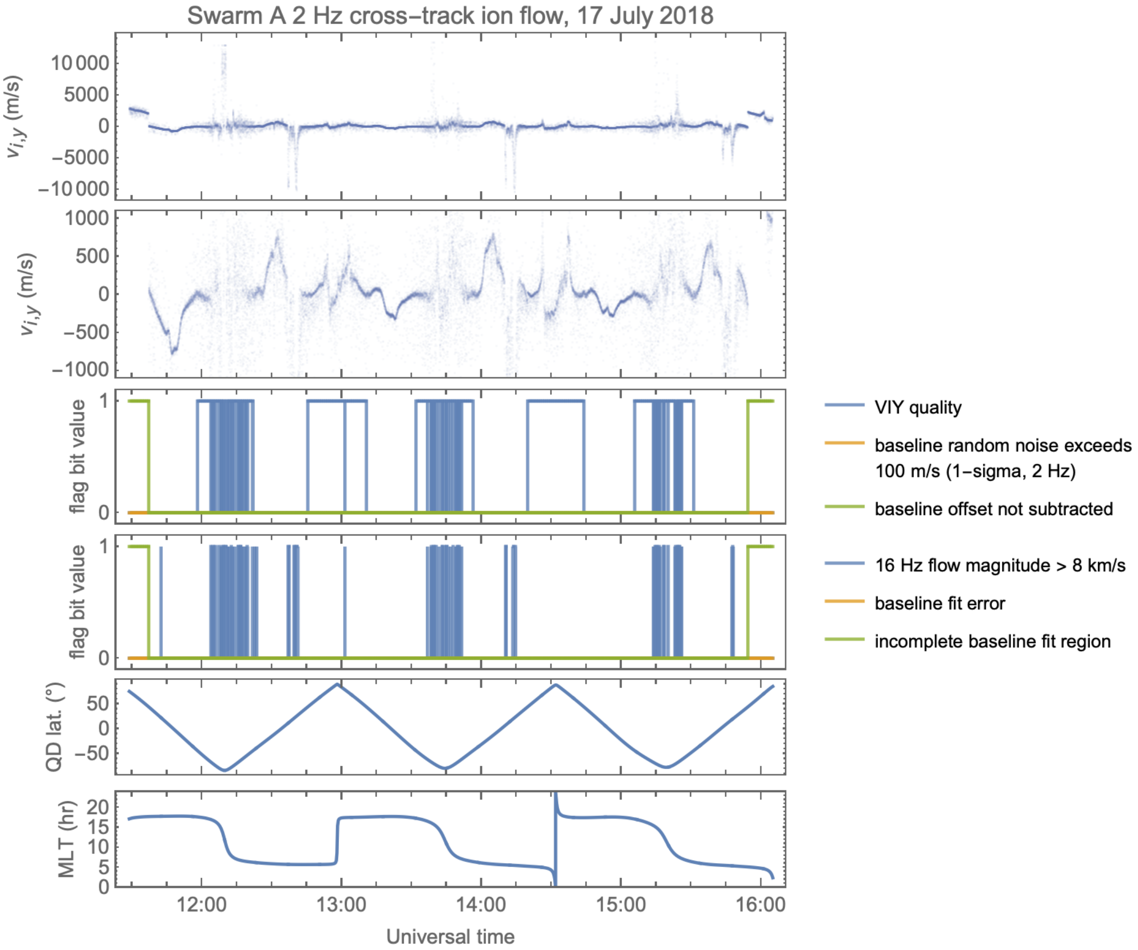


Figure 3-2: Version 0301 cross-track ion flow and quality and calibration flags at 2 Hz from Swarm A on 17 July 2018.

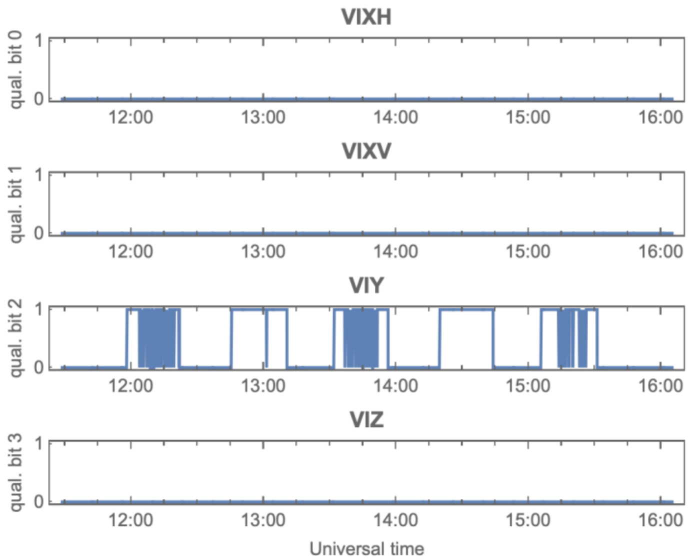


Figure 3-3: Version 0301 quality flags for all four flow measurements at 2 Hz from Swarm A on 17 July 2018.

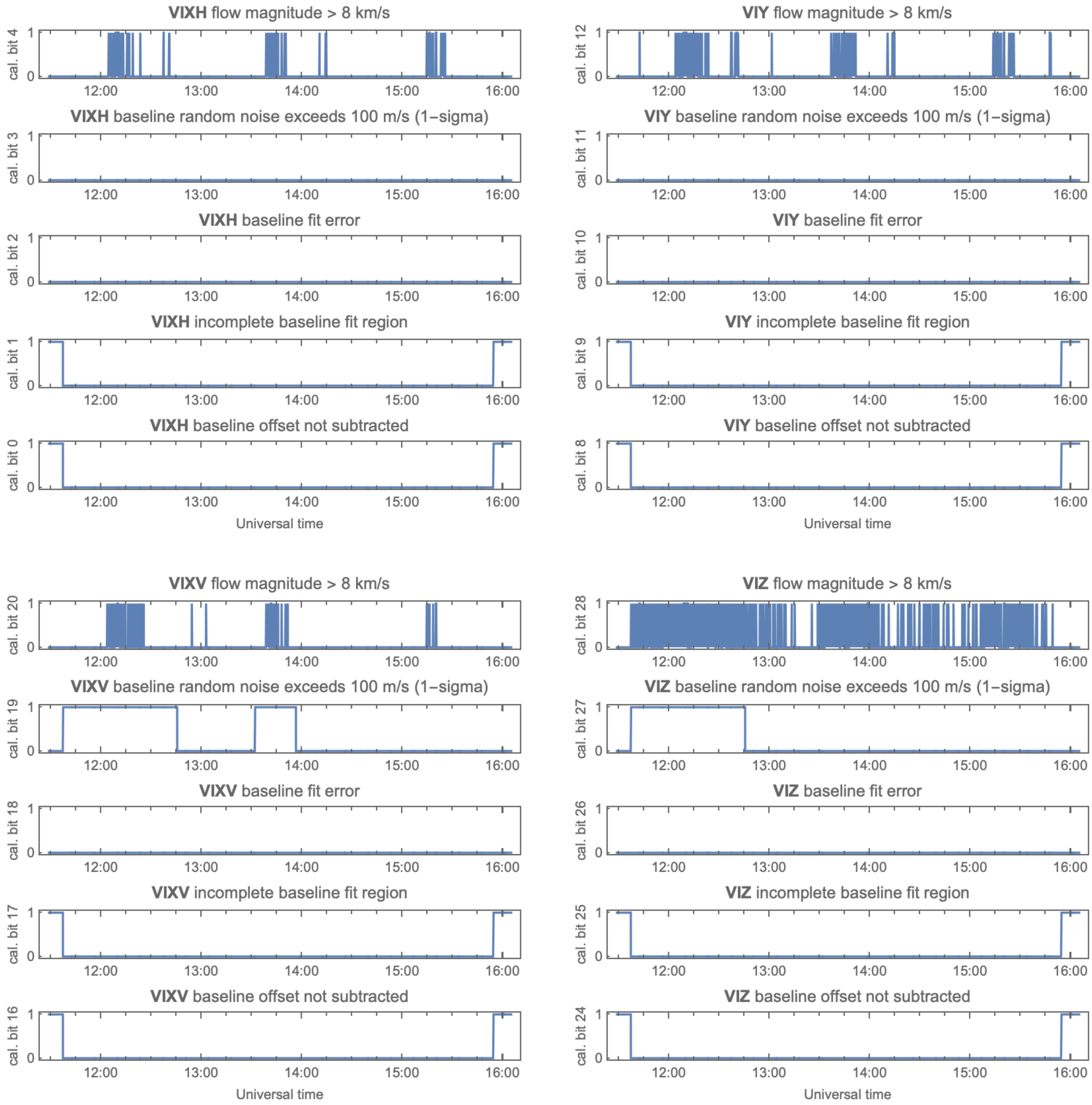


Figure 3-4: Version 0301 calibration flag example for all four flow measurements at 2 Hz from Swarm A on 17 July 2018.

3.4.2 Version 0201

One quality flag is estimated automatically as part of the calibration procedure. The flag is an unsigned 16-bit number whose bits represent the quality of different ion drift components:

- Bit 0 (least significant): $v_{i,x,H}$ (along-track component from the horizontal sensor)
- Bit 1: $v_{i,x,V}$ (along-track component from the vertical sensor)
- Bit 2: $v_{i,y}$ (to the right, observer facing forward)
- Bit 3: $v_{i,z}$ (downward)

The quality of the electric field measurements is to be assessed on the basis of the ion drift quality. It is currently not known which TII sensor provides the most reliable along-track ion drift estimates. The along-track components of ion drift and the electric field components most strongly influenced by them (E_y and E_z) are to be used with caution.

3.4.3 Version 0101

Three quality flags are included for each measurement: qy, qz, and qe represent approximate data quality for the *y* and *z* components of ion velocity and all components of electric field, respectively. Because electric field is derived from both *y* and *z* components of ion velocity, qe is effectively the logical 'AND' of the other two flags. The flag meanings are as follows:

- -1: ion flow measurements lie outside the nominal measurement range of +- 4 km/s; this encompasses both anomalous measurements and large, geophysical flows.
- 0: calibration level 0; do not use in scientific publications except for research into TII imaging anomaly, calibration and validation studies.
- 1: calibration level 1: may contain significant uncorrected biases; the data are often of good quality.
- 2: calibration level 2: horizontal flows are generally of good quality with reasonable baselines; vertical flows may still contain large variations not of geophysical origin. Refer to specific notes in Section 4.

3.5 Data format

3.5.1 Version 0301

Data are provided in files with the following naming convention:

SW_EXPT_EFIX_CCCC_YYYYMMDDTHHMMSS_yyyymmddThhmss_VVVV.cdf

where

- EXPT indicates the data are derived using an experimental processor; processing algorithms, file format, and content may change;
- X is the satellite letter, one of A, B or C;
- CCCC indicates the dataset: TCT16 for 16 Hz, and TCT02 for 2 Hz
- YYYYMMDDTHHMMSS marks the beginning of the interval;
- yyyymmddThhmmss mark the end of the interval;
- VVVV is the dataset version.

Files are split into intervals at midnight UT boundaries. Files are further split at data gaps longer than 10 minutes. Each file is a NASA/CDF file containing the following variables. The files are annotated with global and variable attributes. The 16 Hz (TCT16) and 2 Hz (TCT02) datasets share a common file format.

An overview of the file variables is provided in Table 3-2.

Table 3-2: TII ion drift data NASA CDF file contents version 0301

Variable	Type	Unit	Note
Timestamp	CDF_EPOCH		Time of observation, UTC
Latitude	FLOAT	deg.	Geocentric latitude

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

Variable	Type	Unit	Note
Longitude	FLOAT	deg.	Geocentric longitude
Radius	FLOAT	m	Geocentric radius
QDLatitude	FLOAT	deg.	Quasi-dipole magnetic latitude
MLT	FLOAT	hour	Magnetic local time
Vixh	FLOAT	m/s	Along-track ion drift from horizontal TII sensor in satellite-track coordinates.
Vixh_error	FLOAT	m/s	Random error estimate for along-track ion drift from horizontal TII sensor in satellite-track coordinates. Negative value indicates no estimate available.
Vixv	FLOAT	m/s	Along-track ion drift from vertical TII sensor in satellite-track coordinates.
Vixv_error	FLOAT	m/s	Random error estimate for along-track ion drift from vertical TII sensor in satellite-track coordinates. Negative value indicates no estimate available.
Viy	FLOAT	m/s	Cross-track horizontal ion drift from horizontal TII sensor in satellite-track coordinates.
Viy_error	FLOAT	m/s	Random error estimate for cross-track horizontal ion drift from horizontal TII sensor in satellite-track coordinates. Negative value indicates no estimate available.
Viz	FLOAT	m/s	Cross-track vertical ion drift from vertical TII sensor in satellite-track coordinates.
Viz_error	FLOAT	m/s	Random error estimate for cross-track vertical ion drift from vertical TII sensor in satellite-track coordinates. Negative value indicates no estimate available.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

Variable	Type	Unit	Note
VsatN	FLOAT	m/s	Satellite velocity N component in north-east-centre coordinates.
VsatE	FLOAT	m/s	Satellite velocity E component in north-east-centre coordinates.
VsatC	FLOAT	m/s	Satellite velocity C component in north-east-centre coordinates.
Ehx	FLOAT	mV/m	Electric field *x* component in satellite-track coordinates, derived from -VxB with along-track ion drift from horizontal sensor.
Ehy	FLOAT	mV/m	Electric field *y* component in satellite-track coordinates, derived from -VxB with along-track ion drift from horizontal sensor.
Ehz	FLOAT	mV/m	Electric field *z* component in satellite-track coordinates, derived from -VxB with along-track ion drift from horizontal sensor.
Evx	FLOAT	mV/m	Electric field *x* component in satellite-track coordinates, derived from -VxB with along-track ion drift from vertical sensor.
Evy	FLOAT	mV/m	Electric field *y* component in satellite-track coordinates, derived from -VxB with along-track ion drift from vertical sensor.
Evz	FLOAT	mV/m	Electric field *z* component in satellite-track coordinates, derived from -VxB with along-track ion drift from vertical sensor.
Bx	FLOAT	nT	Geomagnetic field *x* component in satellite-track coordinates, derived from the 1 Hz product.
By	FLOAT	nT	Geomagnetic field *y* component in satellite-track coordinates, derived from the 1 Hz product.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

Variable	Type	Unit	Note
Bz	FLOAT	nT	Geomagnetic field *z* component in satellite-track coordinates, derived from the 1 Hz product.
Vicrx	FLOAT	m/s	Ion drift corotation signal *x* component in horizontal TII sensor coordinates. This has been removed from ion drift and electric field.
Vicry	FLOAT	m/s	Ion drift corotation signal *y* component in horizontal TII sensor coordinates. This has been removed from ion drift and electric field.
Vicrz	FLOAT	m/s	Ion drift corotation signal *z* component in horizontal TII sensor coordinates. This has been removed from ion drift and electric field.
Quality_flags	UINT2	None	Bitwise flag for each velocity component, where a value of 1 for a particular component signifies that calibration was successful, and that the baseline 1-sigma noise level is less than or equal to 100 m/s at 2 Hz. Electric field quality can be assessed from these flags according to -**v**x**B**. Bit0 (least significant) = Vixh, bit1 = Vixv, bit2 = Viy, bit3 = Viz. See Section 3.2.1 of these release notes for details.
Calibration_flags	UINT4	None	Information about the calibration process. See Section 3.2.1 of these release notes for details.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

3.5.2 Version 0201

3.5.2.1 *2 Hz data*

Data are provided in files with the following naming convention:

SW_EXPT_EFIX_TIICT_YYYYMMDDTHHMMSS_yyyymmddThhmmss_VVVV.cdf

where

- EXPT indicates the data are experimental;
- X is the satellite letter, one of A, B or C;
- TIICT indicates this file contains 2 Hz 3D ion flow components;
- YYYYMMDDTHHMMSS marks the beginning of the interval;
- yyyymmddThhmmss mark the end of the interval;
- VVVV is the dataset version, starting with 0201.

Intervals are split at midnight UT boundaries. Intervals are further split at data gaps longer than 10 minutes. Each file is a NASA/CDF file containing the following variables. The files are extensively annotated with global and variable attributes. An overview of the file contents is provided in Table 3-3.

Table 3-3: TII ion drift data NASA CDF file contents version 0201

Variable	Type	Unit	Note
Time	CDF_EPOCH		Time of observation, UTC
Latitude	FLOAT	deg.	Geocentric latitude
Longitude	FLOAT	deg.	Geocentric longitude
Radius	FLOAT	m	Geocentric radius
QDLatitude	FLOAT	deg.	Quasi-dipole magnetic latitude
MLT	FLOAT	hour	Magnetic local time
Vixh_experimental	FLOAT	m/s	Along-track ion drift from horizontal TII sensor in satellite-track coordinates. This is an unvalidated experimental data product.
Vixv_experimental	FLOAT	m/s	Along-track ion drift from vertical TII sensor in satellite-track coordinates. This is an unvalidated experimental data product.
Viy	FLOAT	m/s	Cross-track horizontal ion drift from horizontal TII sensor in satellite-track coordinates.

Variable	Type	Unit	Note
Viz_experimental	FLOAT	m/s	Cross-track vertical ion drift from vertical TII sensor in satellite-track coordinates. This is an unvalidated experimental data product.
Vsatx	FLOAT	m/s	Satellite velocity *x* component in horizontal TII sensor coordinates.
Vsaty	FLOAT	m/s	Satellite velocity *y* component in horizontal TII sensor coordinates.
Vsatz	FLOAT	m/s	Satellite velocity *z* component in horizontal TII sensor coordinates.
VsatN	FLOAT	m/s	Satellite velocity N component in north-east-centre coordinates.
VsatE	FLOAT	m/s	Satellite velocity E component in north-east-centre coordinates.
VsatC	FLOAT	m/s	Satellite velocity C component in north-east-centre coordinates.
Ehx	FLOAT	mV/m	Electric field *x* component in satellite-track coordinates, derived from -VxB with along-track ion drift from horizontal sensor.
Ehy	FLOAT	mV/m	Electric field *y* component in satellite-track coordinates, derived from -VxB with along-track ion drift from horizontal sensor.
Ehz	FLOAT	mV/m	Electric field *z* component in satellite-track coordinates, derived from -VxB with along-track ion drift from horizontal sensor.
Evx	FLOAT	mV/m	Electric field *x* component in satellite-track coordinates, derived from -VxB with along-track ion drift from vertical sensor.
Evy	FLOAT	mV/m	Electric field *y* component in satellite-track coordinates, derived from -VxB with along-track ion drift from vertical sensor.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

Variable	Type	Unit	Note
Evz	FLOAT	mV/m	Electric field *z* component in satellite-track coordinates, derived from -VxB with along-track ion drift from vertical sensor.
Bx	FLOAT	nT	Geomagnetic field *x* component in satellite-track coordinates.
By	FLOAT	nT	Geomagnetic field *y* component in satellite-track coordinates.
Bz	FLOAT	nT	Geomagnetic field *z* component in satellite-track coordinates.
Vicrx	FLOAT	m/s	Ion drift corotation signal *x* component in horizontal TII sensor coordinates. This has been removed from ion drift and electric field.
Vicry	FLOAT	m/s	Ion drift corotation signal *y* component in horizontal TII sensor coordinates. This has been removed from ion drift and electric field.
Vicrz	FLOAT	m/s	Ion drift corotation signal *z* component in horizontal TII sensor coordinates. This has been removed from ion drift and electric field.
flags	UINT2	None	Quality: 0: use with caution, 1: use in consultation with EFI TII team at University of Calgary. Bit0 (least significant) = Vixh, bit1 = Vixv, bit2 = Viy, bit3 = Viz.

Satellite positions are derived and interpolated from the 1 Hz MOD L1b measurements. Magnetic field is interpolated from the 1 Hz low-resolution magnetic field L1b product.

3.5.3 Version 0101

3.5.3.1 *2 Hz dataset*

Data are provided in files with the following naming convention:

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

SW_EXPT_EFIX_TIICT_YYYYMMDDTHHMMSS_yyyymmddThhmss_VVVV.cdf

where

- EXPT indicates the data are experimental;
- X is the satellite letter, one of A, B or C;
- TIICT indicates this file contains 2 Hz horizontal and vertical cross-track ion flow components;
- YYYYMMDDTHHMMSS marks the beginning of the interval;
- yyyymmddThhmmss marks the end of the interval;
- VVVV is the dataset version.

Each file is a GZIP self-compressed NASA/CDF file containing the following variables:

Table 3-4: TII cross-track flow data CDF file contents version 0101

Variable	Type	Unit	Note
timestamp	double	s	2 Hz times are seconds from 1 Jan 2000 00:00:00 UT. To convert to modified Julian day 2000: tMJD2000=Timestamp/86400.
latitude	double	deg.	2 Hz Geocentric latitude, derived from L1b Medium Precise Orbit Determination (MOD) data.
longitude	double	deg.	2 Hz longitude, derived from L1b MOD.
radius	double	m	2 Hz radius, derived from L1b MOD.
qdlat	double	deg.	Quasi-dipole magnetic latitude.
mlt	double	hour	Magnetic local time.
viy	double	m/s	2 Hz ion cross-track horizontal flow speed in co-rotating frame. Positive values are to the right, facing forward.
viz	double	m/s	2 Hz ion cross-track vertical flow speed in co-rotating frame. Positive values are downward.
vsatnorth	double	m/s	Northward component of satellite velocity.
vsateast	double	m/s	Eastward component of satellite velocity (in inertial frame).

Variable	Type	Unit	Note
vsatcentre	double	m/s	Radially inward component of satellite velocity.
vcorotation	double	m/s	Co-rotation signal. Can be added to viy to get approximate horizontal cross-track component of ion velocity in inertial frame of reference.
angleH	double	deg.	Measured velocity flow angle for H sensor, after offset corrections have been applied.
angleV	double	deg.	Measured velocity flow angle for V sensor, after offset corrections have been applied.
offset1h	double	deg.	First level calibration offset correction for H sensor. Negative values represent a subtracted offset.
offset1v	double	deg.	First level calibration offset correction for V sensor. Negative values represent a subtracted offset.
offset2h	double	deg.	Second level calibration offset for H sensor. Negative values represent a subtracted offset.
offset2v	double	deg.	Second level calibration offset for V sensor. Negative values represent a subtracted offset.
ex	double	mV/m	Electric field component parallel to along-track direction in co-rotating frame. Calculated from -vxB assuming along-track ion velocity component is zero.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

Variable	Type	Unit	Note
ey	double	mV/m	Electric field component in cross-track horizontal direction in co-rotating frame. Positive values are to the right facing forward. Calculated from -vxB assuming along-track ion velocity component is zero.
ez	double	mV/m	Electric field component in cross-track vertical direction in co-rotating frame. Positive values are downward. Calculated from -vxB assuming along-track ion velocity component is zero.
bx	double	nT	Magnetic field component in the along-track direction.
by	double	nT	Magnetic field component in the cross-track horizontal direction.
bz	double	nT	Magnetic field component in the cross-track vertical (positive downward) direction.
qy	double	n/a	Quality flag for viy.
qz	double	n/a	Quality flag for viz.
qe	double	n/a	Quality flag for electric field.

Satellite positions are derived and interpolated from the 1 Hz MOD L1b measurements.

3.5.3.2 *16 Hz dataset*

16 Hz data are provided as an additional dataset with a subset of ancillary parameters to allow basic plotting and review of higher-resolution measurements of ion flow and electric field. Quality flags have been interpolated from the 2 Hz dataset and further updated to flag large flows (> 4 km/s) at the higher resolution. Other parameters can be obtained at the higher data rate by suitable interpolation of the corresponding 2 Hz data. High-resolution (50 Hz) magnetic field data are available separately from ESA.

The 16 Hz data are provided in files with the following naming convention:

SW_EXPT_EFIX_TCT16_YYYYMMDDTHHMMSS_yyyymmddThhmss_VVVV.cdf

where

- EXPT indicates the data are experimental;

- X is the satellite letter, one of A, B or C;
- TCT16 indicates this file contains 16 Hz horizontal and vertical cross-track ion flow components;
- YYYYMMDDTHHMMSS marks the beginning of the interval;
- yyyymmddThhmmss marks the end of the interval;
- VVVV is the dataset version.

Each file is a GZIP self-compressed NASA/CDF file containing the following variables:

Table 3-5: 16 Hz TII cross-track flow data CDF file contents version 0101

Variable	Type	Unit	Note
timestamp	double	s	16 Hz times are seconds from 1 Jan 2000 00:00:00 UT. To convert to modified Julian day 2000: tMJD2000=Timestamp/86400.
latitude	double	deg.	16 Hz Geocentric latitude, interpolated from the 2 Hz dataset.
longitude	double	deg.	16 Hz longitude, interpolated from the 2 Hz dataset.
radius	double	m	16 Hz radius, interpolated from the 2 Hz dataset.
viy	double	m/s	16 Hz ion cross-track horizontal flow speed in co-rotating frame. Positive values are to the right, facing forward.
viz	double	m/s	16 Hz ion cross-track vertical flow speed in co-rotating frame. Positive values are downward.
ex	double	mV/m	Electric field component parallel to along-track direction in co-rotating frame. Calculated from -vxB assuming along-track ion velocity component is zero.
ey	double	mV/m	Electric field component in cross-track horizontal direction in co-rotating frame. Positive values are to the right facing forward. Calculated from -vxB assuming along-track ion velocity component is zero.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

Variable	Type	Unit	Note
ez	double	mV/m	Electric field component in cross-track vertical direction in co-rotating frame. Positive values are downward. Calculated from -vxB assuming along-track ion velocity component is zero.
qy	double	n/a	Quality flag for viy.
qz	double	n/a	Quality flag for viz.
qe	double	n/a	Quality flag for electric field.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

4 Dataset Release Notes

Table 4-1: TII cross-track ion flow dataset versions.

Dataset version	Note
0101	Initial release.
0201	Linear rather than angular derivation of cross-track flow. In-flight calibration for Swarm A, B and C cross-track flow sensitivities. Comprehensive mission coverage from December 2013 through December 2019.
0301	Added random error estimates for ion flow based on baseline noise levels. Updated quality flag, including revised random error and flow magnitude thresholds. Added calibration flag. Refined baseline offset estimation algorithm. Removed Vsatx, Vsaty, and Vsatz from CDF. Unified filenames for 2 Hz and 16 Hz datasets. Added new 16 Hz dataset. Updated processing procedure to calibration 16 Hz data, and to derive 2 Hz data by down-sampling the 16 Hz data. Expanded dataset coverage to span 10 December 2013 through 7 June 2020. Corrected flow magnitudes prior to 17 September 2018. Added and corrected text for CDF global annotations. Updated some variable annotations.

Releases are described below with the most recent first.

4.1 Version 0301

4.1.1 Changes

This release uses an updated processing and calibration procedure, described in Section 3.2.1. It corrects a bug in the 0201 processor that resulted in too large ion drift and electric field magnitudes by approximately 35% for measurements made prior to mid-September 2018. A 16 Hz dataset is provided. Calibrations are performed only on the 16 Hz dataset, and the 2 Hz dataset is derived by down-sampling the 16 Hz measurements. Quality flagging has been updated based on the new calibration procedure, and a calibration flag has been added. Ion drift random error estimates have been added. The Vsatx, Vsaty, and Vsatz satellite velocity components have been removed. The "_experimental" suffices on some parameters has been removed as redundant with the "EXPT" designation in the filenames and the details provided in this release note.

4.1.2 Known problems or limitations

Data are provided generally when the EFIs are in normal science mode with high-voltages on. This includes measurements from early December 2013 during EFI power supply commissioning, through the end of the Swarm commissioning in April 2014. These data should be used with caution, irrespective of the quality flag values. In addition, measurements can be affected by experimental operations conducted as part of the EFI TII imaging anomaly review board investigation. Such operations include detector scrubbing, detector rest periods, and changes to the onboard processing settings and detector gain values.

Data coverage is not continuous. Starting in 2015 EFI TII operations have been limited to several orbits per day. Experience has shown that daily rest periods with detector scrubbing operations have the effect of stabilizing the TII imaging performance.

Effort has been made to remove background levels over timescales associated with crossing the polar regions and equatorial regions (4 segments per orbit). Significant non-geophysical offsets can remain, however, and the TII team urges caution in interpreting flow variations spanning timescales larger than a few to 10s of minutes. All measurements at low to mid latitude exhibit large offset variations. Baselines are removed, and all low and mid latitude data quality flags are set to 0.

Along-track and vertical ion flow estimates are provided. As it is not yet possible to confirm the data quality of these measurements, their quality flags are set to 0.

Abrupt changes in ion drift or electric field baselines are associated with the offset removal algorithm. This can be avoided in cases for which the quality flags are always set to 0 by selecting only velocity measurements for which the corresponding "baseline not removed" calibration flag bit is 0 (see Section 3.4.1).

Using the same calibration methodology as Swarm A, the Swarm C cross-track flow magnitudes differ significantly from the Swarm A cross-track flows, based on statistical analysis of the entire dataset. The flow magnitudes ought to be comparable, because the two satellites traverse similar plasma conditions within 10 s of each other at similar altitudes. It is known that the TII sensors perform better after a full orbit of operation, and the fact that Swarm C is typically operated only one orbit is a possible cause of the discrepancy. UCalgary is investigating this difference. In the meantime, the Swarm C cross-track flows are released to the community with all quality flags set to 0. Researchers interested in using the Swarm C cross-track flows should contact the University of Calgary EFI team for assistance in interpreting the observations.

Currently a minimum of 5 minutes of TII data are required for each day's processing. Shorter intervals are not processed, and isolated intervals shorter than 1 minute are not exported.

4.2 Version 0201

4.2.1 Changes

This release uses an updated processing and calibration procedure described above. It includes estimates of along-track ion drift. Drifts are estimated from the TII image moments directly for each cartesian direction, rather than from the ion drift angle, which was the method used for the TIICT 0101 dataset.

4.2.2 Known problems or limitations

Due to a bug in the calibration software for version 0201, the ion drift and electric field magnitudes for data obtained prior to mid-2018 are too large by about 35%. This issue has been corrected in version 0202.

Data are provided generally when the EFIs are in normal mode with high-voltages on. This includes measurements from early December 2013 during EFI power supply commissioning, through the end of the Swarm commissioning in April 2014. These data should be used with caution, irrespective of the quality flag values. In addition, measurements can be affected by experimental operations conducted as part of the EFI TII imaging anomaly review board investigation.

Data coverage is not continuous. Starting in 2015 EFI TII operations have been limited to several orbits per day. Experience has shown that daily rest periods with detector scrubbing operations have the effect of stabilizing the TII imaging performance.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

Effort has been made to remove background levels on an orbital timescale. Significant non-geophysical offsets can remain, however, and the TII team urges caution in interpreting flow variations spanning time-scales larger than a few to 10s of minutes. All measurements at low to mid latitude exhibit large offset variations and are flagged 0.

Along-track and vertical ion flow estimates are provided but have not been validated. The flags for these estimates are set to 0.

Using the same calibration methodology as Swarm A, the Swarm C cross-track flow magnitudes are approximately 67% of the Swarm A cross-track flows, based on statistical analysis of the entire dataset. The flow magnitudes ought to be comparable, because the two satellites traverse similar plasma conditions within 10 s of each other at similar altitudes. It is known that the TII sensors perform better after a full orbit of operation, and the fact that Swarm C is typically operated only one orbit is a possible cause of the discrepancy. Moreover the underestimate appears to be different at different times. UCalgary is investigating this underestimation by the Swarm C sensor. In the meantime the Swarm C cross-track flows are released to the community with all flags set to 0. Researchers interested in using the Swarm C cross-track flows should contact the University of Calgary EFI team for assistance in interpreting the observations.

The CDF file annotations for Vsatx, Vsaty, and Vsatz are incorrectly defined in the satellite-track coordinates. These components are measured in the TII horizontal sensor coordinate system, which differs from the satellite-track coordinate system by the roll, pitch and yaw of the satellite.

4.3 Version 0101

4.3.1 Changes

This is the first release of the TII cross-track ion flow dataset.

4.3.2 Known problems or limitations

Data coverage is not continuous. Starting in 2014 EFI TII operations have been limited to a small number of orbits per day. Experience has shown that daily rest periods have the effect of stabilizing the TII imaging performance.

Effort has been made to remove background levels on an orbital timescale. Significant non-geophysical offsets can remain, however, and the TII team urges caution in interpreting flow variations spanning time-scales larger than a few to 10s of minutes. Horizontal flow data flagged calibration level 2 are for the most part suitable for research and publication (see Figure 4-1, Figure 4-2 and Figure 4-3). The flagging algorithm currently does not perform as well for the vertical flow measurements; an example is the first three days of December 2016 for Swarm A's vertical (*z*) ion flow component in the southern hemisphere where the data have been incorrectly flagged as level 2 (see Figure 4-2). The EFI team continues to work on improving the flagging algorithm, and solicits and welcomes feedback from the scientific community on the data quality.

Because along-track flow is assumed to be the satellite speed (~7.6 km/s), real flow variations in the along-track direction will appear in the cross-track direction when the angle between the ram flow and the satellite x-axis is non-zero. Apparent variations typically not exceeding 100 – 200 m/s in the cross-track flow due to large-amplitude along-track flow variations can be expected mainly at high latitudes.

Due to a bug in the calibration software, the level 1 H sensor flow angles were incorrectly adjusted using the V sensor calibration values. This is expected to have little effect on level 2 (mid- to high-latitude) flows

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

because an additional polynomial background model is subtracted from the level-1 measurements. This bug will be fixed in a future release.

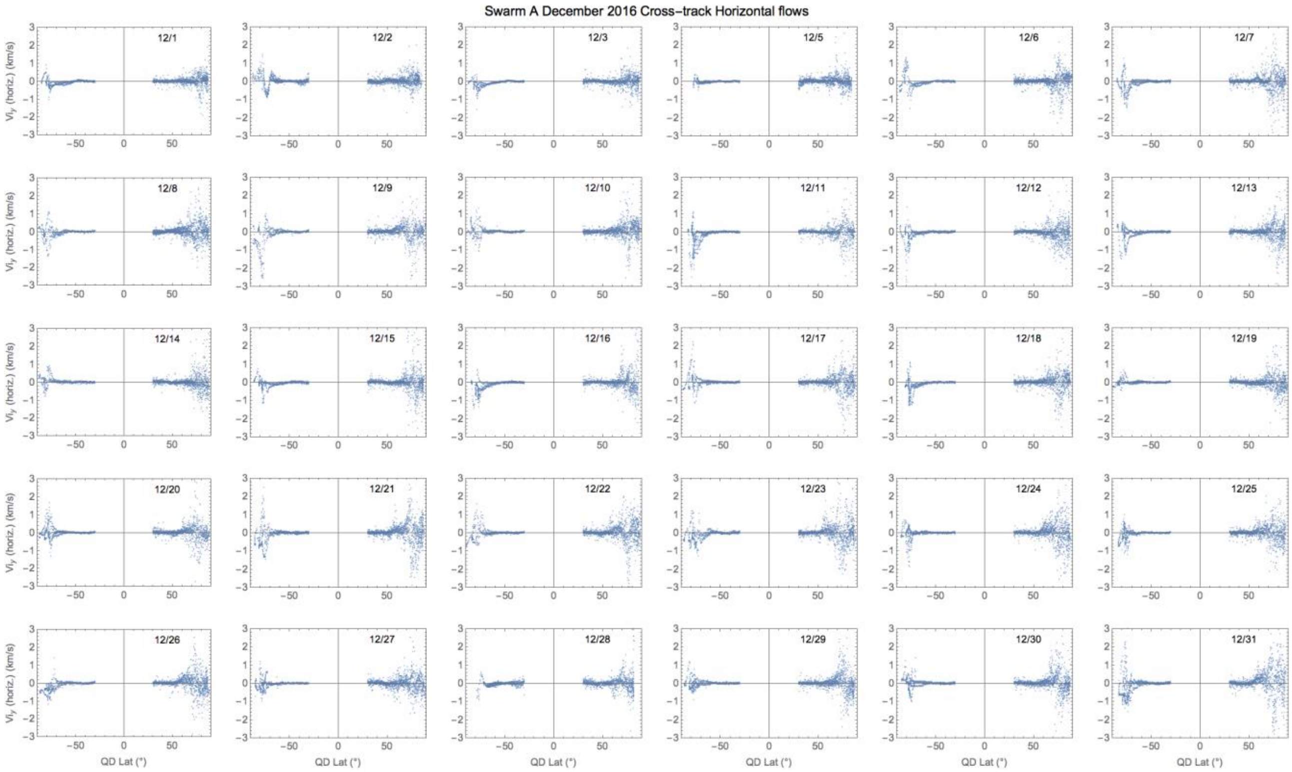


Figure 4-1: Summary of December 2016 Swarm A viy flows flagged as calibration level 2. Positive flows are to the right when facing the direction of travel.

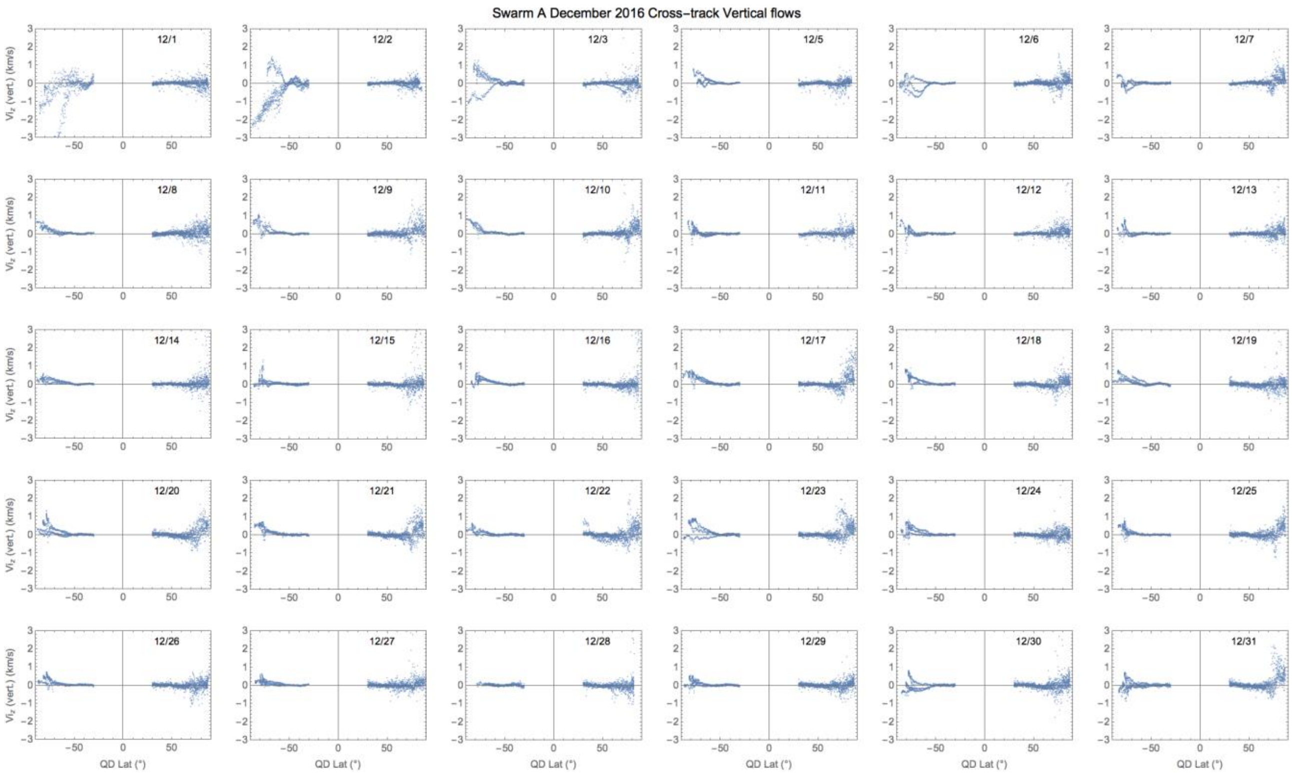


Figure 4-2: Summary of December 2016 Swarm A viz flows flagged as calibration level 2.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.

Positive flows are downward.

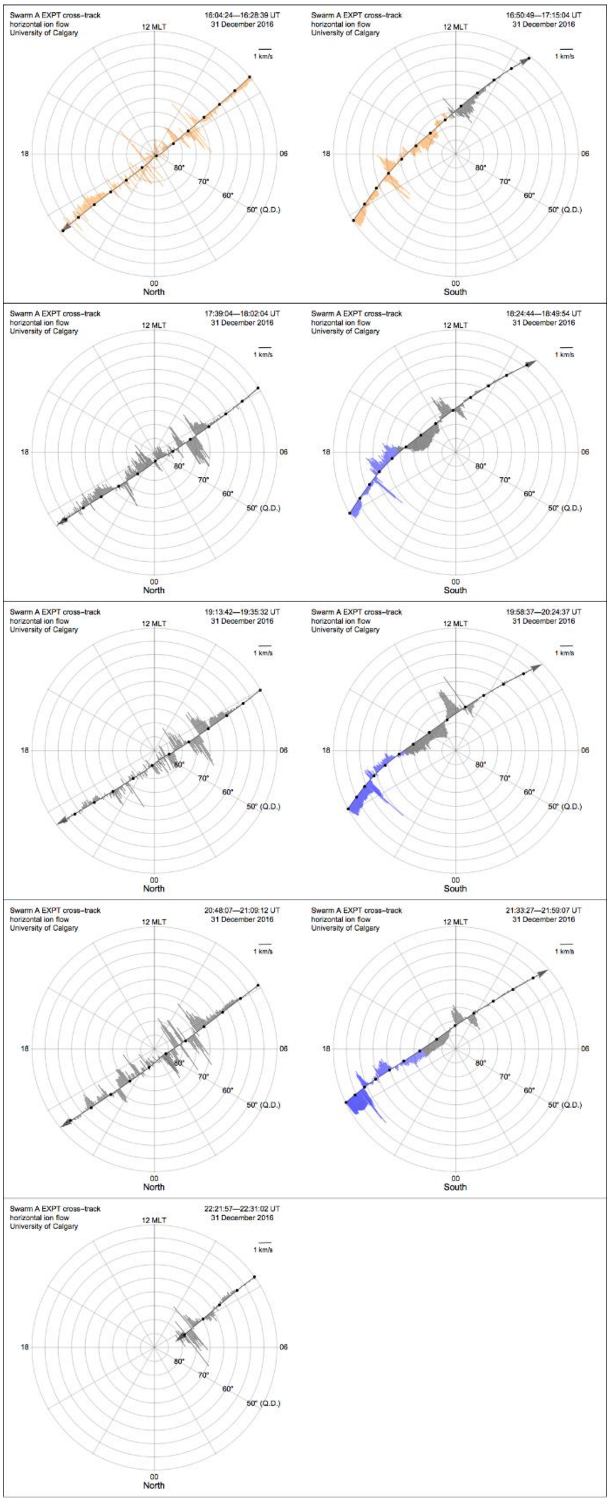


Figure 4-3: Example of ion cross-track horizontal flows from Swarm A on 31 December 2016.

Flows are perpendicular to the satellite trajectory in the co-rotating frame (positive flows point to the right when facing the direction of travel). Flow vectors are colour-coded orange (calibration level 0), blue (cal. level 1), and grey (cal. level 2 or 'good'). MLT, quasi-dipole latitude, hemisphere, velocity scale and time span are indicated on each panel. Black dots mark 2-minute intervals from the start of each track. The satellite moves in the direction of the large arrow at the end of each track.

The use and/or disclosure, etc. of the contents of this document (or any part thereof) is subject to the restrictions referenced on the front page.